Dispersion of Sound in Marine Sediments

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LONG-TERM GOALS

A critical knowledge gap in our understanding of the interaction of sound with the ocean bottom is the frequency dependence of sound speed and attenuation in marine sediments. The long term goals of this research project are related to the investigation of dispersion of sound speed and attenuation at low frequencies (< 2 kHz) in different types of marine sediments. The research involves development of effective experimental methods and inversion techniques to enable estimation of geoacoustic model parameters and their uncertainties over a broad frequency range from tens of Hz to several kHz. The wider context of this research is to achieve improved sonar system performance through greater understanding of the physics of the interaction of sound with the ocean bottom.

OBJECTIVES

The research focus is on inverting modal dispersion relationships to extract geoacoustic model parameters. This approach is well known and has been used to extract information about the ocean bottom from broadband signals measured at long ranges (e.g. several tens of kms) at which the modes are well separated in time. The objective here is to investigate the use of time warping as a means to resolve modes at much shorter ranges. Time warping involves transforming the initial time-frequency domain to a new domain in which the modal dispersion relationships are single tones. Warping is not strongly sensitive to precise knowledge of the experimental geometry (i.e. the source range), and enables resolution of the propagating modes at relatively short ranges. Previous work with time-warping involved transforming the warped modes back into the original time-frequency domain in order to carry out the inversion (Bonnel and Chapman, 2011). The primary objective of this work is to investigate the approach to use the time-frequency information directly in the warped domain for inverting sediment attenuation at low frequencies.

APPROACH

The inversion of geoacoustic model parameters uses broadband data at a single hydrophone at a single range. The approach for inversion from the broadband data is separated into two stages. The first stage inverts for sediment sound speed and density from the time-frequency information in the modal dispersion relationship of the broadband signal in the warped domain. The inversion follows from the simple relationship for the arrival time of the mth mode, t_m, in terms of the warped frequency, ω_w:

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$$t_m(\omega) = t_r \Big/ \sqrt{1 - \left(\omega_w^m / \omega_0\right)^2} \ , \tag{1}$$

where t_r is the time of arrival of the first mode and ω_0 is the frequency component of the signal. The next stage uses the estimated sound speed and density to invert the attenuation of sound in the sediment from modal amplitude ratios

$$R_{m1}(\omega) = \sqrt{\frac{k_1(\omega)}{k_m(\omega)}} \left| \frac{\psi_m(z_s)\psi_m(z_r)}{\psi_1(z_s)\psi_1(z_r)} \right| e^{(\beta_1 - \beta_m)r} . \tag{2}$$

In this inversion, the modal amplitude ratio is sensitive to attenuation through the modal attenuation coefficients, β_m. However, since the modal attenuation also depends upon the sediment sound speed and density, the inversion assumes the estimated values of these quantities from the time-frequency inversion of the modal dispersion relationship.

Implementation of the inversion algorithm was first carried out by simulations to assess the performance in the SW06 experimental environment. The modal amplitude ratio is also sensitive to the source and receiver depths, and the range. Although these quantities can be assumed known from independent measurements, the impact on inversion performance of uncertainty in these parameters is investigated in the simulations. The simulations also tested the impact of range dependence in the sound propagation path. The method was then applied to broadband data from a light bulb sound source deployed in the SW06 experiment. The signal range was ~7 km, and the data were received on the MPL vertical array moored at the MORAY site (Figure 1). Signals from two different light bulbs were used, a G25 with frequency band 100-250 Hz and a G40 with frequency band 80-200 Hz.

WORK COMPLETED

Simulations were carried out to test the implementation of a multi-parameter inversion of the modal amplitude ratio, i.e. assuming source and receiver depths and range are also unknown. Impact of range dependence was tested in simulation using tests with COUPLE97 and Kraken. COUPLE97 was used to generate a broadband signal in a range dependent environment similar to the change in water depth along the propagation path of the light bulb signals deployed in SW06. The simulated broadband data were inverted using Kraken to calculate the signal assuming a range independent propagation path.

The inversion of attenuation was tested in simulations of the SW06 experimental environment assuming that the source range and depth were known. The inversion was then applied to the light bulb data from the experiment to estimate low frequency sound attenuation for the environment in the vicinity of the MORAY site.

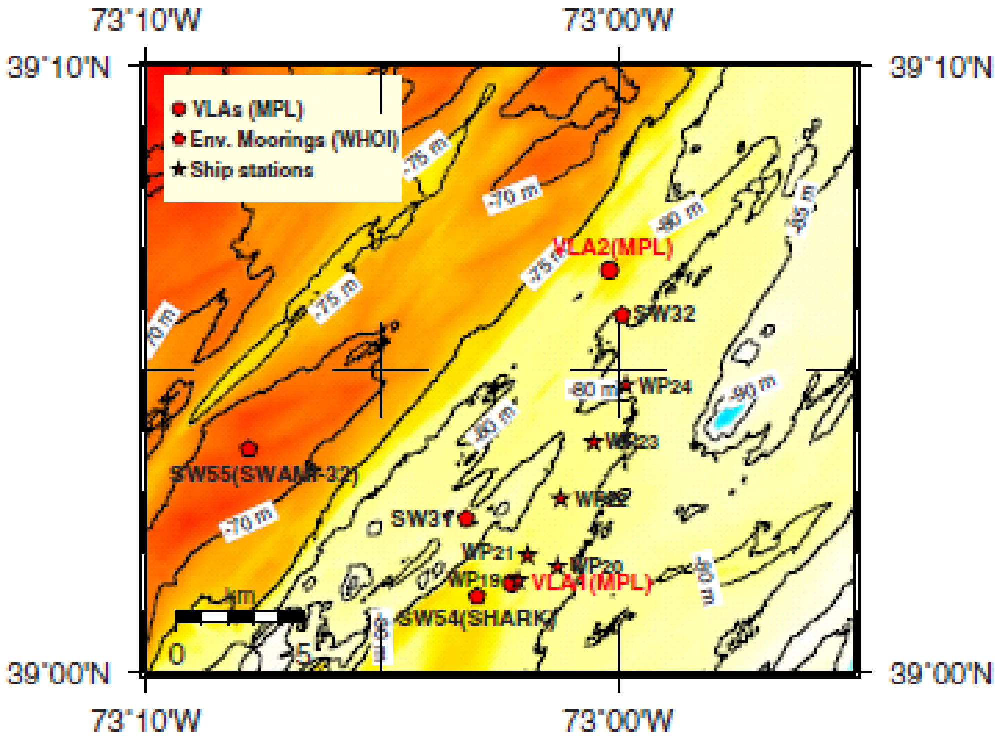

Figure 1. The SW06 experimental site. The light bulb deployment site is near position WP24.

RESULTS

The multi-parameter inversion approach for estimating attenuation from the modal amplitude ratio was not stable in estimating reliable values for the unknowns. However, receiver depth of hydrophones on a vertical array can be estimated directly from the data by inverting the ratio of modes for hydrophones separated by one receiver-element spacing. From (2) there is only one unknown, since the array element spacing is measured and known. Investigation of the sensitivity to source depth is continuing. The results of the different inversions for sound attenuation are listed in Table 1 for an inversion of simulated data in a frequency band centred at 160 Hz. The first inversion assumes that the experimental geometry of the source and receiver are known; the second assumes known receiver depth and the third assumes source and receiver depths are unknown. In all cases, simple grid searches were used in the inversions. The estimated modal amplitude ratios are very close to the theoretical values. Although the simulated results show reasonable performance for all the inversions, application to experimental data was successful only for the first and second inversions.

The two-stage inversion for sound attenuation in marine sediment assuming estimated values of sound speed and density proved to be stable and effective. The inversions in each stage use different quantities from the broadband data: the first inversion of the modal dispersion uses time-frequency information that is independent of the attenuation; the impact of attenuation is obtained from the second inversion that uses modal amplitude information.

Table 1. Results of inversions of simulated data

160 Hz	Modal ratios to mode 2				1	2		3		
	M1	M2	M3	M4	atten	atten	zs	atten	zr	zs
Exp	0.361	1	0.877	0.21	0.08	0.14	21.4	0.1	67.8	23.1
Theory	0.390	1	0.888	0.191	0.1	0.1	22	0.1	67	22

The range dependence of the water depth along the propagation path was tested using COUPLE97 to generate a broadband signal in the frequency band 40-350 Hz. The measured bathymetry from the SW06 experiment was used in the test (Goff et al, 2004). Figure 2 shows the comparison between the spectra in the warped domain for the signal simulated by COUPLE97 and one simulated by Kraken assuming range independence and the mean depth between the source and receiver. The spectra are in close agreement, as might be expected for the weak range dependence along the propagation path (about 2.5 m over 7 Km).

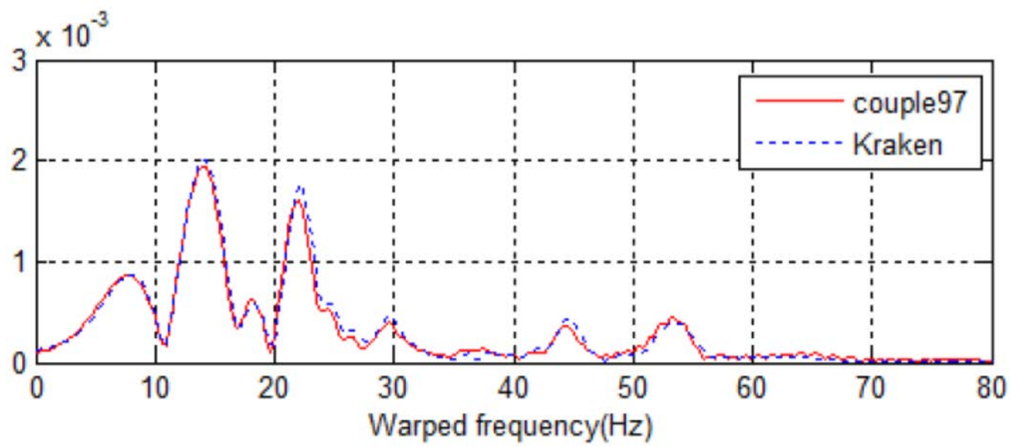

Figure 2. Comparison of the spectra in the warped domain for a range dependent environment (COUPLE97) and a range independent environment (Kraken).

The results for low frequency sound attenuation from inversion of broadband light bulb data are indicated by the black squares in Figure 3. Also shown in the figure are results from different inversions for comparison. The broken green line is from the matched field inversion of Jiang and Chapman (2009); the blue squares are from the spectral ratio inversions of Turgut (2008); the red squares are the travel time inversions of Jiang and Chapman (2010) and the black line is the prediction of Carey for the New Jersey shelf region (Dediu et al, 2007). Although these results for the low frequency attenuation are very preliminary, they are consistent with the low values in the vicinity of this site from the inversions of higher frequency data. Work is continuing to test the impact of other factors on the inversion, such as, (1) the source waveform; and (2) the size of the frequency band in estimating modal amplitudes from the spectrum in the warped domain.

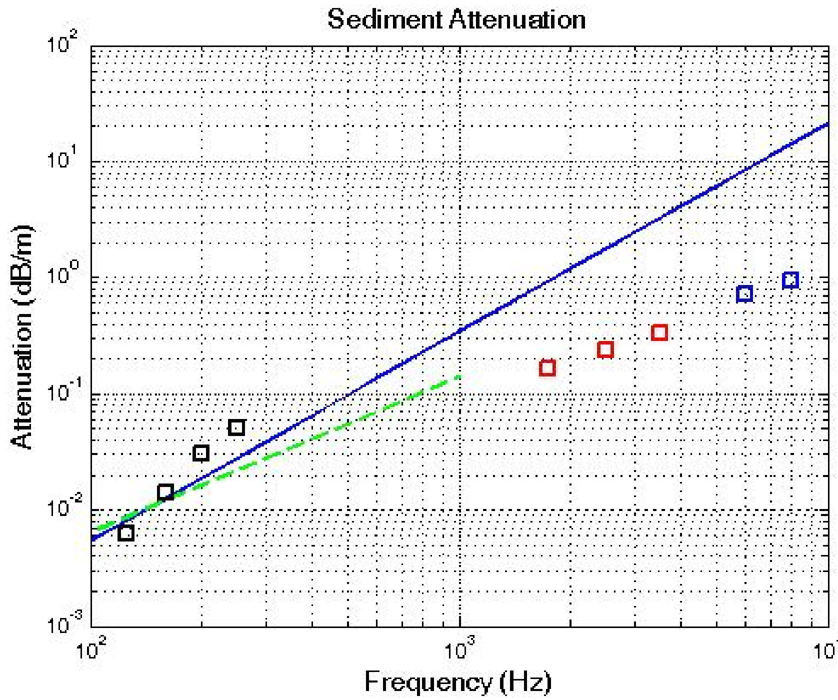

Figure 3. Estimated attenuation from (1) modal amplitude ratios (black squares); spectral ratios (blue squares); travel time sub-bottom signal (red squares); matched field inversion (green line). The black line is the predicted attenuation from Carey.

IMPACT/APPLICATIONS

Inversion of mode amplitude ratios obtained by time-warping of broadband data is a promising technique for estimating sound attenuation in marine sediments at low frequencies. The method is insensitive to exact knowledge of the experimental geometry and sound speed in the water, and can provide high resolution modal data at relatively short ranges.

RELATED PROJECTS

The knowledge gained in this work will identify gaps in our understanding that can be addressed in designing the next phase of experiments. The research is connected with research projects of the following: W. S. Hodgkiss and P. Gerstoft (MPL, SCRIPPS); D. Knobles (ARL:UT); G.V. Frisk (Florida Atlantic); P. Dahl and D.J. Tang (APL UW); J. Miller and Gopu Potty (University of Rhode Island), J. Goff (U of Texas at Austin) and J. Lynch (WHOI). The overall goal of this group is to characterize the geoacoustic environment and understand mechanisms of the interaction of sound with the ocean bottom.

Links have also been made with other researchers supported by ONRG. Dr Laurent Guillon spent a 6-month sabbatical at UVic to collaborate in development of his image method for geoacoustic inversion. A paper is being written to summarize the research carried out over the visit. Data from SW06 was shared with Dr Michael Taroudakis in collaborative work on a new inversion technique.

The broadband light bulb data were supplied to him for use a sound source in a test of the inversion technique with experimental data. A paper to summarize the work was submitted to JASA EL.

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